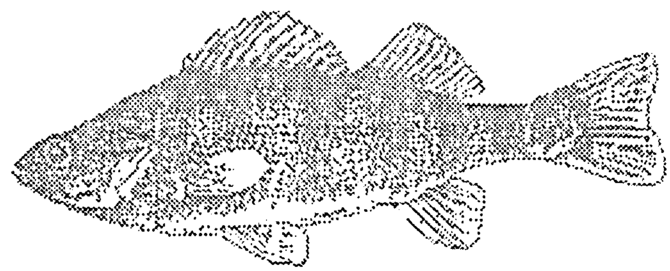
ILLINOIS NATURAL HISTORY SURVEY

Yellow Perch Growth—A Collaboration Initiative

Aquatic Biology Section
Technical Report

William H. Horns
Principal Investigator

Final Report
F-63-R



Aquatic Biology Technical Report 89/3

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William H. Horns
Aquatic Biology Section
Illinois Natural History Survey

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William H. Horns
Principal Investigator
Aquatic Biology Section
Illinois Natural History Survey

Lewis Osborne
Section Head
Aquatic Biology Section
Illinois Natural History Survey

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Abstract

Yellow perch aged 3-8 were collected by gill netting in Illinois, Indiana, Michigan, and Wisconsin waters of southern Lake Michigan during fall of 1986, spring and fall of 1987, and spring of 1988. Ages determined by cracking sagittae through the long axis, burning an exposed face, and counting annuli under magnification proved verifiable and valid. Analysis of lengths, weights, condition factors, and first-annulus diameters indicated the following: 1) Year-class strength influences size-at-age, but the effect may be moderated by fishing. 2) Size-at-age was least in Indiana despite warmer temperatures and good first-year growth, suggesting an impact by the fishery. 3) But Indiana fish were also in poorer condition than contemporaries in Illinois and Wisconsin, suggesting that one or more other factors were also influential. 4) Lee's phenomenon was not conspicuous in any state, especially Indiana. 5) The pattern of differences in first-year growth suggest that intra-specific competition rather than alewife predation controls mean size-at-age after the first year, if yearlings and yoy compete for food. 6) First-year growth is not a dominating factor in later size-at-age.

Introduction

Background

Southern Lake Michigan is divided into four fisheries management jurisdictions, those of Michigan, Indiana, Illinois, and Wisconsin. Throughout the period of this study the intensity of fishing for yellow perch differed sharply among the four states, ranging from light in Michigan to heavy in Indiana, with intermediate levels in Illinois and Wisconsin. In Michigan waters no commercial fishing was allowed. Indiana, which has the shortest shoreline on Lake Michigan, allowed by far the largest commercial harvest. With the increasing abundance of yellow perch in the 1980's the reported commercial catch of yellow perch in Indiana rose from 92,000 pounds in 1978 to 1,000,000 pounds in 1984, and exceeded 1,300,000 pounds in both 1986 and 1987 (Brazo 1988). Illinois and Wisconsin allowed intermediate harvests. In Illinois 130,000 to 193,000 pounds were taken annually during the 1984-1987 period (Hess 1989) while in Wisconsin waters south of Green Bay the harvest ranged from 270,000 pounds in 1984 to 542,000 pounds in 1987 (Belonger *et al.* 1989). Sportfishing harvests do not compensate for these differences in commercial harvests. In 1987 the estimated sport harvests (in pounds) were 548,000 in Michigan (derived from Rakoczy 1988), 38,000 in Indiana (Brazo 1988), 419,000 in Illinois (Horns 1988), and 160,000 in Wisconsin (Belonger 1989).

Wells (1985,1988) states that concurrent with a decline in alewife abundance in southern Lake Michigan, yellow perch became more abundant and slower growing. He reports strong year classes in 1983 through 1986 and notes that near Saugatuck, Michigan, the average length of yellow perch of the 1983 year class caught at the end of their third growing season was 5.9 inches, nearly 30% less than fish of the same age caught in the same area in the 1970's. McComish (1986) documented strong yellow perch year classes in 1983 and 1984 and also reported a decline in size-at-age in those fish. Similar data are not available for Wisconsin and Illinois, although Belonger *et al.* (1988) also reported an exceptionally strong 1983 year class in Wisconsin waters.

Intraspecific competition may explain the reported decline in size-at-age associated with increasing abundance; the fish may simply grow slower when too many of them are competing for a limited food supply. Two other mechanisms, decreasing size-related predation by alewives on yoy yellow perch and increasing size-related commercial harvesting of adults, may also be important.

<u>Size-related predation</u>. Brandt *et al.* (1987) showed that in Lake Ontario alewives are capable of eating large numbers of yellow perch fry, but only when the yellow perch are under 0.35 inches in length. The increase in yellow perch abundance in southern Lake Michigan in the 1980's was associated with a decrease in alewife abundance (Jude and Tesar 1985, Wells 1985). These facts suggest that alewives when abundant were able to limit yellow perch abundance by direct predation. Since predation by alewives is limited to the smallest yellow perch, it can be imagined that it influenced the size distribution of each year class by removing smaller individuals disproportionately. Perrone *et al.* (1983) state that during the 1970's inland-spawned yellow perch contributed significantly to the population in

Lake Michigan. If alewife predation did not affect those fish, which hatched earlier and were therefore larger than their lake-spawned counterparts, it influenced the final yellow perch size distribution through selective removal of the later spawning and therefore smaller lake-spawned component of the population.

Commercial harvest. Fishing is highly size-selective and therefore tends to remove the larger and faster growing members of each year class. It is therefore not surprising that during a period of increasing commercial fishing pressure in Indiana the size-at-age of yellow perch declined.

The validity of any study of yellow perch growth depends on the accuracy of the methods used to determine the ages of the specimens. Historically, the age of yellow perch in Lake Michigan has been derived from scales and assumed to be correct. Recent work has indicated that otolith-derived age can be more accurate than scale-derived age for Percids. Heidinger (R.C. Heidinger, Southern Illinois University - Carbondale, personal communication) found 100% agreement between known-age and otolith-derived age of walley in a power cooling lake. The ages derived from scales were correct only 75% of the time. Scale annuli from known-age fish have been inconsistent indicators of age, even in relatively young fish (Prather 1967, Taubert and Tranquilli 1982, Goeman *et al.* 1984).

Objectives

This study was initiated with the following three objectives in mind: 1) To establish in southern Lake Michigan a system of coordinated data collection that utilizes the resources and common interests of fishery managers and scientists in four states. 2) To assess the potential for sport and commercial fishing to influence yellow perch growth in Lake Michigan. 3) To evaluate the accuracy, for yellow perch, of age determinations based on scales.

Methods

Lake Michigan Littoral Fisheries Research Group

Coordination and planning for this study were largely accomplished through the Lake Michigan Littoral Fisheries Research Group, an informal association of fisheries managers and scientists that met twice annually starting in the spring of 1985. Meetings of LMLFRG served as forums for discussion of the project during both planning and execution. Through these meetings we were able to develop a plan of fish collections under which comparable collection methods were employed in all of the states. Collections were made by Mike Coshun of the Wisconsin Department of Natural Resources, Rich Hess of the Illinois Department of Conservation, Dan Brazo of the Indiana Department of Natural Resources, and Dave Jude of the University of Michigan.

Aging Methods

Scales and unprepared otoliths

A random sample of 1090 of the yellow perch collected in the fall of 1986 as described below were aged by Dr. Roy Heidinger of Southern Illinois University using, independently, both scales and otoliths (sagittae). The scales were projected using a microfiche reader while the otoliths were broken through the anterior-posterior axis and examined, aided by light concentrated by an optical fiber, under magnification.

Burned otoliths

All estimated ages ultimately used in this study were derived from otoliths using a "crack and burn" method. Otoliths were held in water prior to final preparation for reading. One sagitta from each fish was cracked through the anterior-posterior axis and as close as possible to the nucleus Figure 1. Usually the posterior half was examined, although when one half contained the entire nucleous, that half was examined. The exposed face of the half to be examined was burned briefly in a flame from an alcohol lamp and the fragment was embedded in wax with the burned face up. That surface was then wet with immersion oil and examined, aided by light concentrated by an optical fiber, at between 10X and 60X magnification. All counts of annuli were made in the ventral field (Figure 1). Apparent annuli were only counted when a) they were conspicuous in the ventral field and b) they were also apparent somewhere in the dorsal field. All otoliths were read independently by two readers. This report contains only data for fish to which both readers assigned the same age. Otoliths were read in random order. At the time of reading, the readers knew the year and season during which the fish was captured, but had no other knowledge of the fish. When spring-caught fish were aged, the edge of the otolith was counted as an annulus when an appreciable space was present between the edge and the outermost visible annulus.

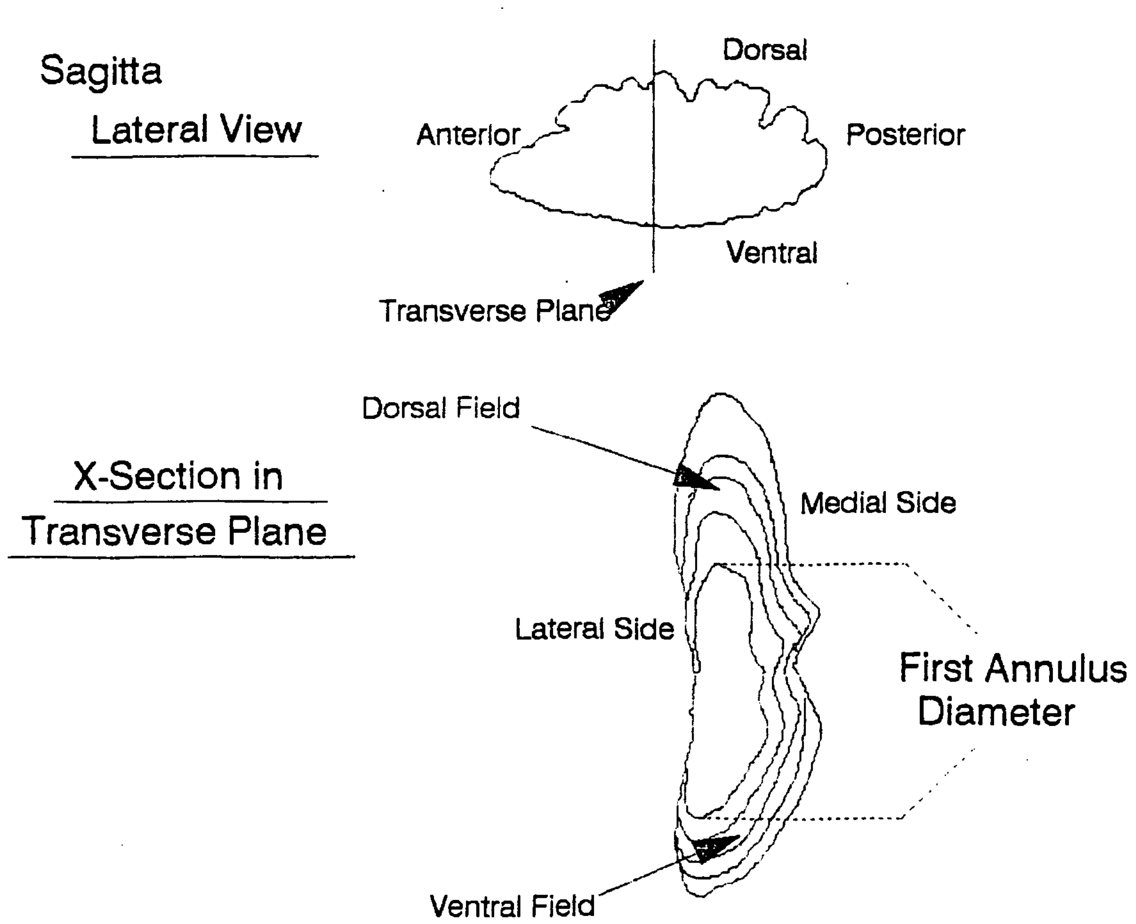

Figure 1. Whole otolith (sagitta) in lateral view and cross section.

One hundred fish were aged a second time by one of the readers. In this exercise a random sample of 25 fish were selected from each of the four collection periods (fall 1986, spring 1987, fall 1987, and spring 1988). For each fish the sagitta not used in the initial reading was used. The 100 otoliths were read in random order so that the reader was not only ignorant of the physical characteristics of the fish, as was the case in all readings, but he also had no knowledge of the year and season of capture. In this exercise the edge was never counted as annulus as described above, but a note was made if the outermost annulus was at the margin of the otolith. After all 100 readings were completed one year was added to the estimated age of all spring-caught fish which did not have an annulus at the outer margin.

For each otolith the diameter of the first-annulus (defined as illustrated in Figure 1) was also measured. To provide a basis for assessing whether or not we were correctly identifying the first annulus, otolith heights along the dorsal-ventral axis were measured from burned sagittae taken from 10 yoy yellow perch collected in Illinois on September 19, 1986 and from 8 yearling yellow perch collected in Illinois on June 23-24, 1986.

Fish Collections

Collection gear and sampling methods

All fish collections were made with graded-mesh gill nets hung on the half basis, weighted with lead weights, and meeting the following specifications:

number of panels - seven.
mesh sizes (stretch measure) - 1.50", 1.75", 2.00", 2.25", 2.50", 2.75", 3.00".
panel lengths (in order of increasing mesh sizes) - 50', 50', 100', 100', 100', 100', 100'.

With the exception of nets used in Indiana during fall 1986 and spring 1987 collections, all nets were like-new (95% intact or better) and built of 210/2 bonded monofilament nylon with panel heights (in order of increasing mesh size) of 40, 30, 31, 25, 25, 24 and 20 meshes. Nets used in Indiana during the first two sampling periods (fall 1986 and spring 1987) differed from the others in the following respects: 1) The 1.5" panels were built of twine cut down to 24 meshes. 2) the 1.75" panels were built of twine 28 meshes high. 3) All panels with mesh sizes larger than 1.75" were low-profile (i.e., 18-24 meshes deep) nets that were built of 210/3 monofilament nylon twine and that might have been less than 95% intact.

Nets were always set overnight, with direction of sets with respect to the shoreline left to the discretion of the crew and, therefore, varying from time to time and place to place.

Sub-sampling

At most 25 yellow perch were retained from each panel lifted. In most cases when a panel contained more than that number, the first twenty five encountered as the net was taken into the boat were selected. In the fall of 1986 the subsamples taken in Illinois and Wisconsin were selected haphazardly after all fish had been cleared from the nets. Total catch, by mesh size, was always recorded so that the subsampling fraction (number of fish kept divided by total number caught) could be computed and used in computing weighted averages of the dependent variables (see below, "Corrections for subsampling, net length, and selectivity")

Study design

In each of the four states two or four transects were defined (Figure 2). Nets were always set on those transects, with sets at approximately 10 m in all states and other depths left to the descretion of the state biologist in charge of collections. Transects within a state were always separated by at least one mile. Table 1 summarizes the dates and locations of gill-net lifts from which data used in this report were derived.

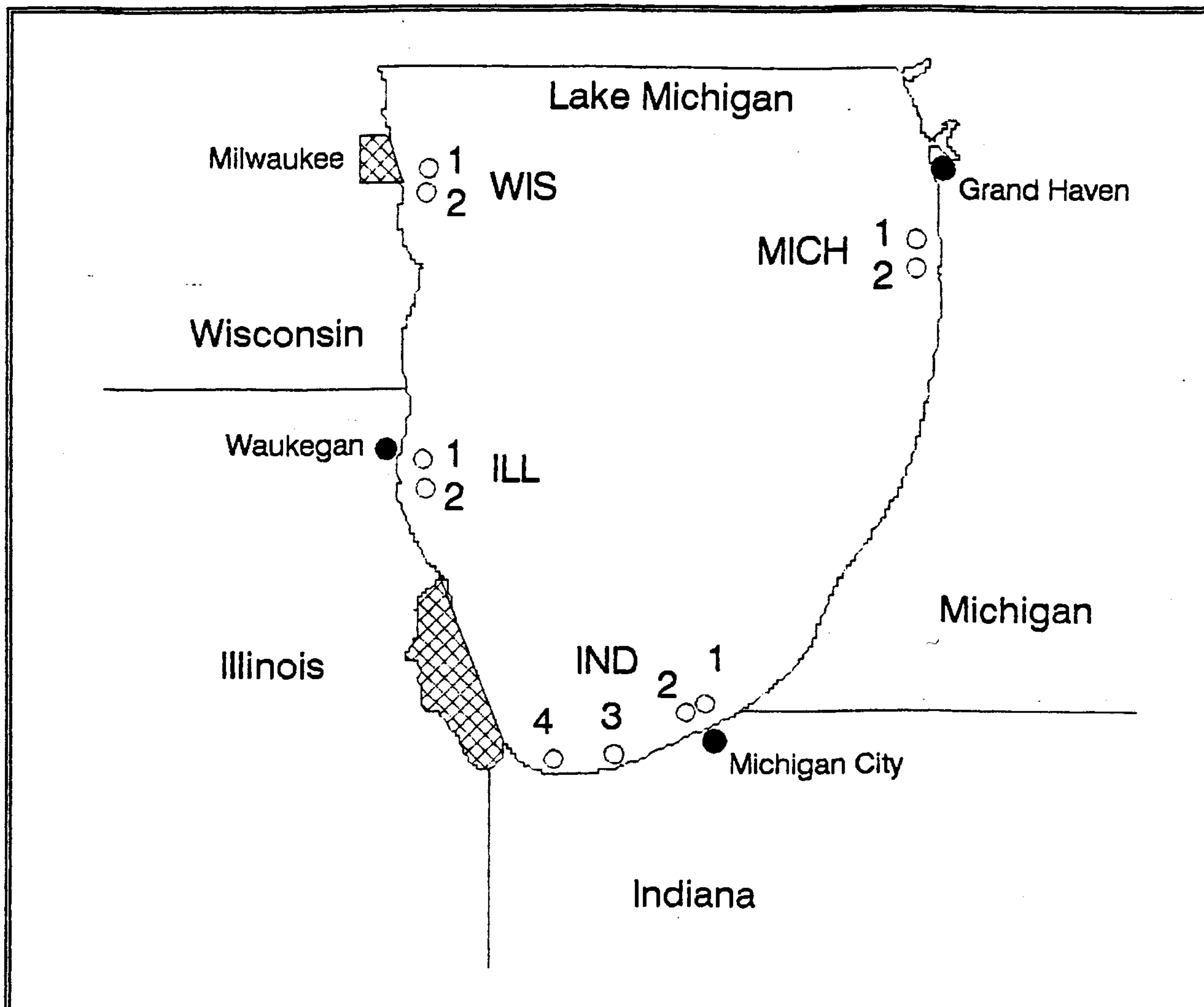

Figure 2. Locations of gill-net lifts.

Season	State: Illinois	Indiana	Michigan	Wisconsin
FALL '86	9/30 10m ILL-1 9/30 10m ILL-2 9/30 20m ILL-1 9/30 20m ILL-2	9/26 11m IND-1		9/30 7m WIS-1 9/30 9m WIS-1 9/30 6m WIS-2 9/30 9m WIS-2
SPR '87	6/3 10m ILL-1 6/3 10m ILL-2	6/2 9m IND-1 6/2 18m IND-1	6/16 5m MIC-1 6/16 10m MIC-1	6/17 9m WIS-2 6/17 15m WIS-2 6/18 9m WIS-1 6/18 11m WIS-2
FALL '87	9/22 10m ILL-1 9/22 20m ILL-1		9/17 5m MIC-2 9/17 10m MIC-2	
SPR '88	5/25 10m ILL-1 5/26 10m ILL-1 5/26 10m ILL-2 5/31 10m ILL-1 6/1 10m ILL-1 6/1 10m ILL-2 5/25 20m ILL-1 5/31 20m ILL-1	6/1 10m IND-2 6/7 10m IND-3 6/7 10m IND-4 6/15 10m IND-1 6/1 20m IND-2 6/7 20m IND-3 6/7 20m IND-4 6/15 20m IND-1	6/3 5m MIC-2	6/1 10m WIS-2 6/1 13m WIS-2 6/2 10m WIS-1 6/2 10m WIS-2 6/7 8m WIS-2 6/7 10m WIS-2

Table 2. Summary of gill-net lifts. For each season and state, the dates, depths, and transects of all gill-net lifts are shown.

Handling and preservation of fish

As fish were removed from the gill nets they were segregated with regard to mesh size by placement in separately marked ziploc plastic bags and placed on ice in coolers. Within 24 hours those bags were double-wrapped in large plastic bags and frozen. The fish were sometimes kept frozen for several months before they were weighed, measured, and dissected.

Dependent Variables

During dissection otoliths and scales were removed, sex was determined, and several variables were measured. In addition to those listed below, several variables not analyzed for this report were measured; those were total gonad weight, total stomach weight (contents plus stomach), liver weight, and gonad condition.

Variables that were measured and have been used in this report are total length, total weight, and visceral-fat weight. For each fish a condition factor equal to weight (in pounds) divided by length (in inches) cubed was derived. Visceral-fat weight was converted to visceral-fat percentage (100 times visceral-fat weight over total weight). Age and first-annulus diameter were derived from otoliths as described above. For several hundred fish of varying ages and sizes maximum girth was also measured. This was to allow the calculation of the relationship between girth (as a dependent variable) and length and weight (as independent variables). This was needed to allow the use of girth in selectivity calculations (see below, "Corrections for subsampling, net length, and selectivity"). The relationship derived was the following:

$$girth = - 0.20 + (3.13 * (weight)^{1/3}) - (0.12 * length),$$

where girth is measured in centimeters, weight is measured in grams, and length is measured in centimeters.

First-annulus diameter corresponds to otolith height at the time of first annulus formation. We found that in 28 fall yoy and spring yearling yellow perch otolith height was strongly correlated with fish size (product moment correlation coefficient = 0.96, n = 28), and therefore inferred that first-annulus diameter is a valid index of first-year growth.

Data Reduction

Use of the individual lift as the sampling unit

In the analyses presented below, the individual gill-net lift is the sampling unit. That is, for each separate lift (including all seven mesh sizes) an average value (weighted as described below) for each dependent variable was computed for each age and sex combination. Thus, for example, we computed a weighted average length of 5-year-old males collected in the lift from 10m on transect ILL-1 on September 30, 1986. For each lift, a similar weighted average was computed for all age and sex combinations and for all dependent variables.

Corrections for subsampling, net length, and selectivity

The averages so computed were weighted to account for a) sub-sampling fraction, b) panel length (1.5" and 1.75" panels were only half as long as the other mesh sizes), and c) gill net selectivity.

The selectivity of a gill net panel for fish of a given size (length or girth) is a product a) the probability that a fish of that size encounters the panel and b) the probability that a fish of that size is retained by the net after the encounter (Rudstam *et al.* 1984). The selectivity of an entire graded mesh gill net for a fish of a given size is the sum of the selectivities of each panel. Corresponding to each of three selectivity functions (i.e., three assumptions about these probabilities), I computed a complete set of weighted averages for each dependent variable.

In the first selectivity function, both the probability of encounter and the probability of retention were assumed to be independent of fish size (*i.e.*, constant). In the second, the probability of encounter was constant but for each mesh size the probability of retention was the following function of maximum girth and gill-net mesh size:

$$\text{Prob. ret.} = A_2 * (1 + (x - 1.19)/0.7)^{28} * (1 + (x - 1.19))/22)^{880},$$

where x is the ratio of maximum girth to gill-net mesh perimeter and A_2 is a constant. This function was obtained by Barry Johnson (Center for Limnology, University of Wisconsin, personal communication) by fitting a Pearson Type I equation (Hamley and Regier 1973) to the selectivity curve for yellow perch presented in Figure 4 in Berst (1961). Note that this probability was computed for each mesh size, regardless of where (in what mesh) the fish was found, and that the probabilities so computed were summed across all mesh sizes. In the third selectivity function the foregoing retention probability was used and the probability of encounter was the following function discussed by Rudstam (1984):

Prob. enc. $= A_1 * l^{1.6}$,

where l is total length and A_1 is a constant. Values of A_1 and A_2 can be arbitrarily set because they cancel-out in computations of weighted averages. I set those values to 1.

In the computation of weighted averages (for each selectivity function) each measured value (the value of one variable measured on one fish) was weighted by the product of 1/L, 1/F, and 1/S, where

L = 0.5 if the fish was taken in 1.5" or 1.75" mesh, and 1 otherwise,

F = the subsampling fraction (number kept/number caught) for the gill net panel from which the fish was taken, and

S = the value of the selectivity function corresponding to the fish's girth.

The same considerations and methods were applied in the calculation of indicies of catch-per-effort for each age and sex combination for each lift. In these computations the weighted average of an indicator variable was computed, with the indicator variable given the value 1 for every fish.

In the analyses presented below weighted averages computed using the second selectivity function (equal encounter probabilities but unequal retention probabilities) were used.

Comparison of Selectivity Functions

The data presented below were derived using a selectivity function in which encounter probability is assumed to be constant, but where retention probability is a function of girth and mesh size. As described above, two other selectivity functions were also tried. Figure 3 presents some of our data as computed under each of the three functions. All selectivity functions yield similar figures.

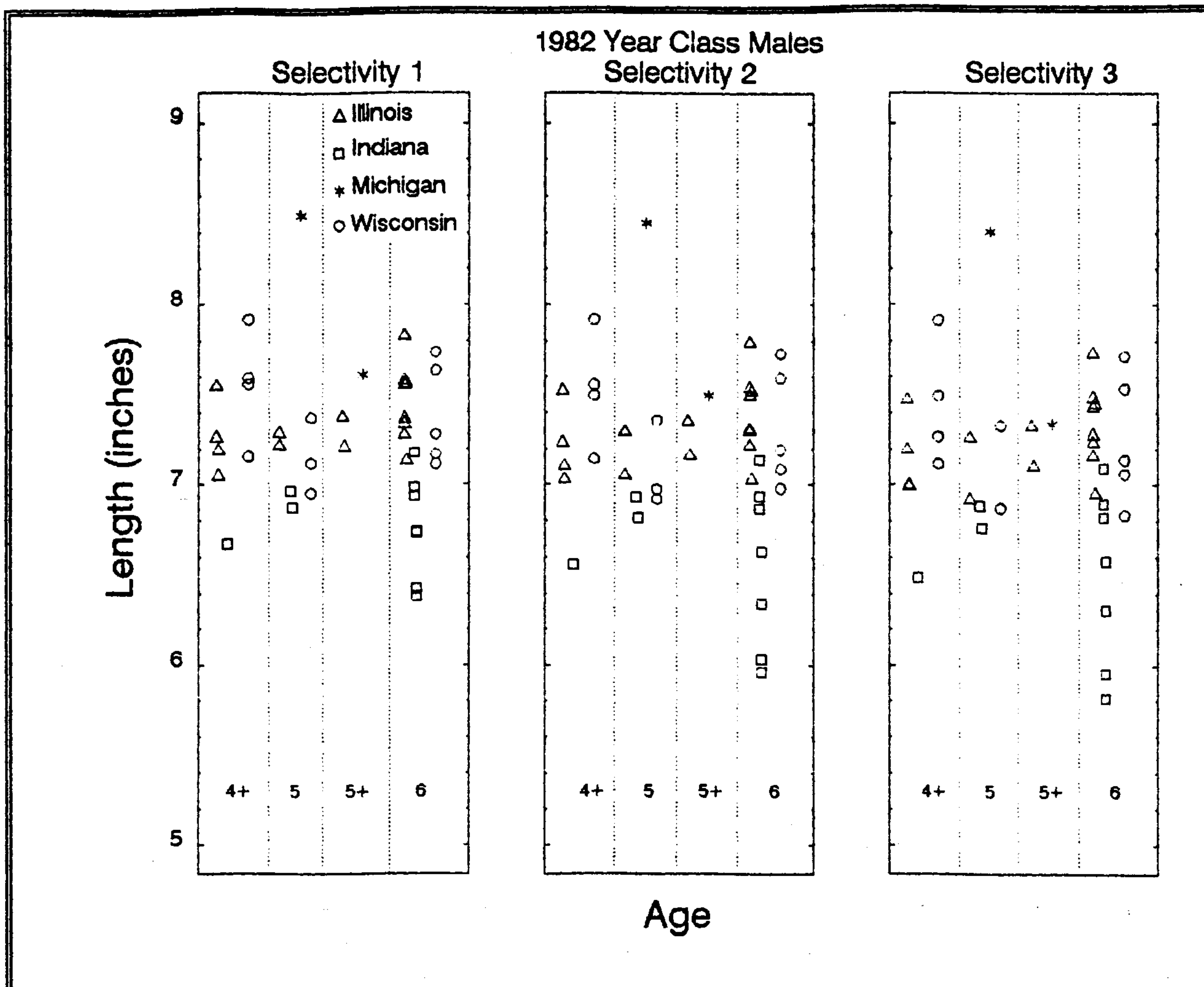

Figure 3. Mean lengths computed under three selectivity functions. Selectivity 1 - encounter and retention probabilities constant; Selectivity 2 - encounter probabilities constant but retention probabilities depend on girth; Selectivity 3 - encounter probabilities depend on length and retention probabilities depend on girth.

Exclusion of low-catch weighted averages

When the number of fish of any specific age and sex caught in an entire lift was less than 3, the weighted averages for that age and sex combination in that lift were not used in the analyses described below.

Statisical Analyses

The weighted averages computed as described above formed the basis for all statistical analyses described here. All statisical analyses described here were performed separately for males and females.

Only three year classes, 1982, 1983 and 1984, contributed significantly to our catches. For each of those year classes the ages of fish that were available to this study are summarized below. For each year class and age this table shows the collection season (f86 = fall 1986, s87 = spring 1987, etc.) during which fish of that year class and age were available to us.

age:	2+	3	3+	4	4+	5	5+	6
1982 year class					f86	s87	f87	s88
1983 year class			f86	s87	f87	s88		
1984 year class	f86	s87	f87	s88				

The younger fish of the 1984 year class (two- and three-year-olds) were caught in such low numbers that they could not contribute significantly to any analyses.

For each variable (length, weight, condition factor, visceral-fat percentage, and first-annulus diameter) two types of analysis were conducted. These analyses were conducted separately for each sex: 1) Data from the 1982 and 1983 year classes were analyzed (separately) for evidence that the states differed with respect to the variable of interest over the ages available (4+ through 6 for the 1982 year class and 3+ through 5 for the 1983 year class). 2) Data for 4+ and 5-year-old fish and, separately, 3+ and 4-year-old fish were analyzed for evidence that year classes differed with respect to the variable of interest. The 4+ and 5-year-old fish provided the basis for comparing the 1982 and 1983 year classes and the 3+ and 4-year-old fish provided the basis for comparing the 1983 and 1984 year classes.

Comparison of states within year classes

For each year class (1982 and 1983) separately the "extra sum of squares" principle (Draper and Smith 1981, page 87) was used to compare three linear models:

1) $x_{ijk} = M + A_i + S_j + AS_{ij} + e_{ijk}$,

2) $x_{ijk} = M + A_i + S_j + e_{ijk}$,

3) $x_{ijk} = M + A_i + e_{ijk}$.

In these models x_{ijk} represents the weighted average of the variable of interest as observed in fish of age i taken in the kth replicate lift from state j, M represents an overall mean value, A_i represents a deviation from the overall mean associated with fish of age i, S_j represents a deviation from the overall mean associated with fish from state j, and AS_{ij} is an interaction term associated with the combination of age i and state j. F-statistics were used to compare the abilities of the three models to explain the data. When the states differed, but not equally at all ages, the interaction terms (the AS's) were large and F-statistics comparing models 1 and 2 tended to be large. When the states differed significantly, but equally at all ages, the interaction terms were small and the state-effect terms (the S's) were large; F-statistics comparing models 1 and 2 tended to be small and those comparing models 2 and 3 tended to be large. When the states did not differ, all F-statistics tended to be small.

Comparisons of year classes

The 1983 and 1984 year classes were compared using 3+ and 4-year-olds. The 1982 and 1983 year classes were compared using 4+ and 5-year-olds. For each comparison three linear models were compared:

1) $x_{ijkl} = M + AS_{ij} + C_k + ASC_{ijk} + e_{ijkl}$,

2) $x_{ijkl} = M + AS_{ij} + C_k + e_{ijkl}$,

3) $x_{ijkl} = M + AS_{ij} + e_{ijkl}$.

In these models x_{ijkl} represents the weighted average of the variable of interest as observed in fish of age i and year class k taken in the lth replicate lift from from state j, M represents an overall mean value, AS_{ij} represents a deviation from the overall mean associated with fish of age i from state j, C_k represents a deviation from the overall mean associated with fish from year class k, and ASC_{ijk} is an interaction term associated with the combination of year class k and age-state ij. F-statistics were used to compare the abilities of the three models to explain the data. When the year classes differed, but not equally at all age-state combinations, the interaction terms (the ASC's) were large and F-statistics comparing models 1 and 2 tended to be large. When the year classes differed significantly, but equally for all age-state combinations, the interaction terms were small and the year-class-effect terms (the C's) were large; F-statistics comparing models 1 and 2 tended to be small and those comparing models 2 and 3 tended to be large. When the states did not differ, all F-statistics tended to be small.

Consideration of depth

Depth may be a significant factor. In preliminary runs of these models it appeared that yellow perch of some ages caught in 20 meters of water were shorter and lighter than those of the same age caught in the same state but in 10 meters of water. In order to prevent this from confounding the comparisons of interest, all statistical tests reported here involving length and weight were made using only data from collections made in water of 15 meters of less. All graphical displays of the data distinguish deep-water lifts (> 15 m) from others.

Consideration of differences in sampling dates

Within sampling seasons the dates of collections sometimes differed by as much as three weeks. The statistical analyses in this report make no correction for differences in sampling dates. I believe that any effects of differences in sampling dates were small. Figure 3 provides some assurance on this point.

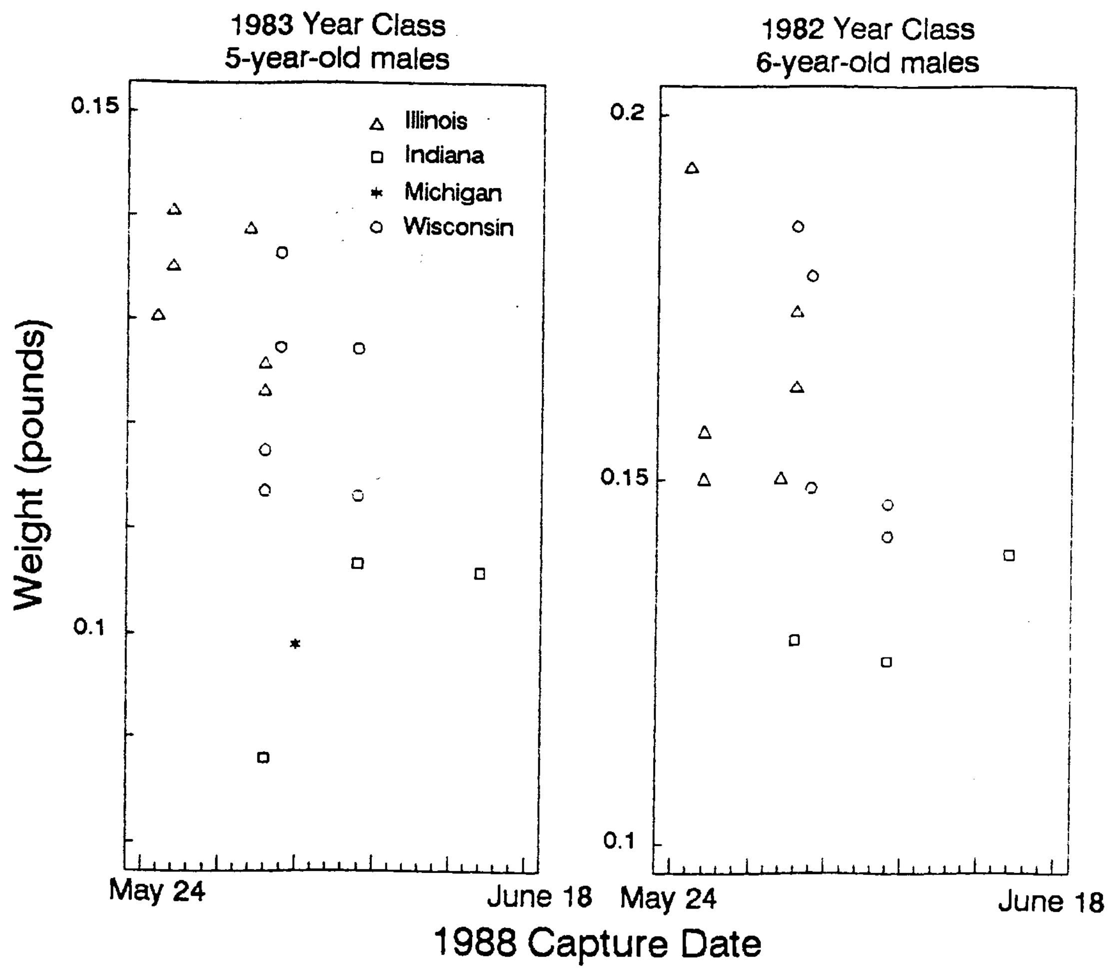

Figure 3. Weighted mean lengths of 5- and 6-year-old males collected on several dates 1988 in four states.

Missing Data

The figures and tables below reflect some missing data. In some cases estimates are not available because a state was not sampled during one season. Data are missing for this reason from Michigan for fall 1986 and from Indiana and Wisconsin for fall 1987. In other cases data are not shown here because a weighted mean was excluded from analyses and graphical presentations when the number of fish contributing to the mean was less than 3. This exclusion rule affected two of the dependent variables, first-annulus diameter and percent visceral fat, more than the others because we were more often unable to measure first-annulus diameter and visceral fat than the other variables. The exclusion rule was not applied to catch-per-effort data.

Results

Age Determinations

Ages determined from scales and unprepared otoliths differed, but both erroneously indicated a dominant 1982 year class in Illinois.

1090 yellow perch collected in the fall of 1986 from Indiana, Illinois, and Wisconsin (563 females and 527 males) were aged by Dr. Roy Heidinger using scales and cracked but unburned otoliths. He found agreement between the two methods in 46% of the females and 57% of the males. The modal age was 4+ for both males and females, suggesting a dominant 1982 year class.

First-annulus diameters derived using the crack and burn method were similar to whole-otolith heights of fall yoy and spring I+ yellow perch.

The mean height (measured along the dorsal-ventral axis and therefore corresponding to first-annulus diameter) of burned sagittae from ten yoy yellow perch collected in Illinois on September 19, 1986 was 0.040 inches. The mean height for seven yearling fish collected on June 23-24, 1986 was 0.055 inches. Most weighted mean first-annulus diameters derived from fish caught in Illinois in this study fall between those two values (Figure 8).

Ages derived by the crack and burn method were highly reproducible.

In this study fish the two independent readers agreed on ages of over 85% of all fish, with the agreement rate reaching 90% in groups of fish aged last.

When a random sample of 100 fish were re-aged in random order by a trained reader agreement was found in 92 cases. This good agreement occurred despite the facts that a) the reader had no knowledge of the fish (*i.e.*, its physical characteristics, its date of capture, *etc.*) or of the first reading at the time of the second reading and b) the two ages were derived from different otoliths.

Ages derived by the crack and burn method correctly indicated a strong 1983 year class in all four states.

During all sampling periods the 1983 year class formed the most abundant age-class; in fall 1986 3-year-old fish were most abundant, in spring and fall 1987 4-year old fish were most abundant and in spring 1988 5-year-olds were most abundant (Table 2). None of the four states deviated from this pattern, which applied to both sexes (with only one exception: in spring 1988 5-year-old females in Indiana were outnumbered by 3-year-olds). This indication of a strong 1983 year class is consistent with independent reports from Michigan (Wells 1985), Indiana (McComish 1986), and Wisconsin (Belonger *et al.* 1989).

	age	Illinois f	Illinois m	Indiana f	Indiana m	Michigan f	Michigan m	Wisconsin f	Wisconsin m
FALL 1986	2+	0	0	10	0			3	2
	3+	17	32	283	53			59	48
	4+	6	11	63	44			2	14
	5+	0	0	0	0			0	2
	6+	0	11	0	37			0	15
	7+	0	0	0	0			0	0
	8+	0	0	0	0			0	0
SPRING 1987	2	0	0	0	0	0	0	0	0
	3	0	36	0	39	0	0	1	9
	4	18	309	14	77	140	2	16	112
	5	1	83	3	22	13	1	1	11
	6	0	0	0	1	0	0	0	0
	7	0	50	0	3	0	2	0	9
	8	0	2	0	0	0	0	0	0
FALL 1987	2+	22	33			4	0		
	3+	16	44			20	0		
	4+	65	146			104	5		
	5+	6	62			18	3		
	6+	0	0			0	0		
	7+	2	9			1	0		
	8+	0	0			0	0		
SPRING 1988	2	0	5	15	12	0	0	0	0
	3	7	115	64	84	7	4	3	56
	4	4	89	19	99	2	3	5	55
	5	14	398	20	324	8	11	8	248
	6	1	109	1	103	0	0	1	35
	7	0	8	0	10	0	0	0	0
	8	0	28	0	4	0	0	0	21

Table 2. Average catch-per-effort, by collection period and age. Data from deep (> 20m) lifts excluded. Estimates derived using the second selectivity function (*i.e.*, equal encounter probabilities assumed).

Relative Abundance

There is no clear evidence for differences among the states in abundance of males.

Catches of yellow perch in gill nets are highly erratic, and provide poor estimates of relative abundance. While it is clear that the 1983 year class was much stronger than that of 1982 (Table 2), I do not believe that we have clear evidence of differences among the states. Our most complete sampling series was in the spring of 1988. In that sample Illinois, Indiana, and Wisconsin yielded similar catch rates of both males and females, although Wisconsin's catches were slightly below the other states (Table 3). We were forced to exclude from analysis one of two lifts made in Michigan during that spring collection series, because one of the seven gill net panels was missing, but that lift was comparable to those in the other states both in number of fish and in sex ratio.

Year Class	season	age	Illinois f	Illinois m	Indiana f	Indiana m	Michigan f	Michigan m	Wisconsin f	Wisconsin m
1982	fall '86	4+	6	11	63	44			2	14
	sprg '87	5	1	83	3	22	13	1	1	11
	fall '87	5+	6	62			18	3		
	sprg '88	6	1	109	1	103	0	0	1	35
1983	fall '86	3+	17	32	283	53			59	48
	sprg '87	4	18	309	14	77	140	2	16	112
	fall '87	4+	65	146			104	5		
	sprg '88	5	14	398	20	324	8	11	8	248

Table 3. Average catch-per-effort, by year class and age. Data from deep (> 20m) lifts excluded. Averages derived using the second selectivity function (*i.e.*, equal encounter probabilities assumed).

Catch curves increase

In view of the potential effects on catch rates of seasonal patterns in yellow perch movements and sexual segregation, fall and spring data must be considered separately in assessing patterns in relative abundance. For each year class therefore we have two catch curves, each with at most two points. The catch curves can be visualized from the data in Table 3. One puzzling feature of the catch curves is the fact that older fish were consistently caught in larger numbers than younger fish from the same year class. Only the youngest cohorts were less than fully vulnerable to our gill nets (Figure 5), so I would have expected to see catch rates decrease with increasing age. The opposite occurred.

Figure 5. Length frequency distributions of 3-, 4-, and 5-year-old yellow perch caught in the spring of 1988 in Illinois.

Sex ratios reflected in gill net catches differed among the four states.

Males tended to outnumber females, expecially in spring catches (Table 3). Michigan was an exception to this rule, with females dominating in most lifts. (The data shown here are somewhat misleading because I have excluded one Michigan lift from the spring of 1988, a lift that was almost exclusively males. Those data were excluded because one panel was mistakenly left out of the net.) In Indiana our sample of fall 3-year-olds from the 1983 year class was dominated by females.

Dependent Variables

All statistical tests referred to here are summarized in Table 4. The data are summarized and displayed in Figures 6-10 and Tables 5-9.

Year classes differed in length, weight, and condition factor.

Both males and females of the 1983 year class were shorter, lighter, and in poorer condition than those of the 1982 year class ($p < 0.01$, all tests). Comparisons of these cohorts involved 4+ and 5-year-old fish. Length differences ranged from 0.3 inches (5-year-old Illinois and Wisconsin males) to 1.5 inches (5-year-old Michigan females). Weight differences ranged from 0.02 pounds (5-year-old Illinois and Wisconsin males) to 0.18 pounds (5-year-old Michigan females). Significant interactions between year class and age-state combination reflect these among-state differences in response to increasing abundance.

Females of the 1984 year class were longer and heavier than those of the 1983 year class ($p < 0.01$), while males of those year classes did not differ in length and weight. Comparisons of these cohorts involved 3+ and 4-year-old fish. Wisconsin's 4-year-old females showed the greatest differences in length (0.6 inches) and weight (0.07 pounds). With regard to condition factor, significant interactions between year class and age-state ($p < 0.01$) reflect the fact that while condition factors in Illinois and Indiana continued to decline (no data available for Michigan) those in 4-year-olds from Wisconsin (both males and females) were higher for the 1984 year class than the for 1983 year class.

States differed in length, weight, and condition factor.

The four states differed with regard to length, weight, and condition of the 1983 year class ($p < 0.01$, all tests). In these comparisons, yellow perch from Indiana tended to be shorter, lighter, and thinner than those of Illinois and Wisconsin, although they compared favorably with those of Michigan. By age 5, Indiana males of the 1983 year class were 0.4 inches shorter than those in Illinois, and 0.03 pounds lighter. The picture is less clear for the 1982 year class. There the four states differ significantly in length and weight of males ($p < 0.01$, both tests), but not of females. Here the dominant features seem to be small Indiana males and very large Michigan males and females. Indiana females of the 1982 year class compare favorably with those of Illinois and Wisconsin.

Year classes and states differed in first-annulus diameter.

Males, but not females, of the 1983 year class had smaller first-annulus diameters than those of the 1982 year class ($p < 0.01$). The difference was greatest for 5-year-old Michigan males. Both males and females of the 1984 year class had smaller first-annulus diameters than those of the 1983 year class ($p < 0.01$, both tests).

The four states differed with regard to first-annulus diameters of both males and females of the 1983 year class ($p < 0.01$). Diameters from Indiana tended to be larger than from Illinois and Wisconsin. In this year class, diameters were largest in females from Michigan. The four states differed with regard to first-annulus diameters of females ($p < 0.01$) but not males of the 1982 year class. In this year class diameters from Michigan tended to exceed those from the other states.

Year classes and states differed in percent visceral fat.

The 1982 and 1983 year classes did not differ significantly in this variable. Differences between the 1983 and 1984 year classes were not the same for all age-state combinations ($p < 0.05$ in interaction tests for both males and females). For both 1982 and 1983 year classes, males of the four states differed significantly in percent visceral fat ($p < 0.01$ for 1982 and $p < 0.05$ for 1983). In those groups Michigan fish showed particularly low values while Illinois values tended to be high, particularly in the fall. In females of the 1983 year class interactions between state and age where highly significant ($p < 0.01$).

In Indiana waters during the spring of 1988 yellow perch caught in 20 meters of water were consistently smaller than fish of the same age caught in 10 meters of water.

In four pairs of lifts, one from 10 m and one from 20 m, taken in Indiana in the spring of 1988, weighted mean lengths of 5- and 6-year-old males taken from 20 m were always less than those of fish of the same age taken from 10 m. Data for fish from the deep stations were excluded from the statistical analyses summarized above.

	Comparing States Within Year Classes			Comparing Year Classes		
		F-tests			F-tests	
Variable	Group (yr class,sex)	int	main	Group (yr.classes,sex,ages	int	main
length	1982 females	ns	ns	82-83, females, 4+ & 5	ns	**
	1982 males	ns	**	82-83, males, 4+ & 5	**	**
	1983 females	ns	**	83-84, females, 3+ & 4	ns	**
	1983 males	ns	**	83-84, males, 3+ & 4	ns	ns
weight	1982 females	ns	ns	82-83, females, 4+ & 5	*	**
	1982 males	*	**	82-83, males, 4+ & 5	**	**
	1983 females	ns	**	83-84, females, 3+ & 4	ns	**
	1983 males	ns	**	83-84, males, 3+ & 4	ns	ns
1st ann.	1982 females	ns	**	82-83, females, 4+ & 5	ns	ns
	1982 males	ns	ns	82-83, males, 4+ & 5	ns	**
	1983 females	ns	**	83-84, females, 3+ & 4	ns	**
	1983 males	ns	**	83-84, males, 3+ & 4	ns	**
condition	1982 females	ns	ns	82-83, females, 4+ & 5	**	**
	1982 males	*	ns	82-83, males, 4+ & 5	ns	**
	1983 females	**	**	83-84, females, 3+ & 4	**	ns
	1983 males	**	**	83-84, males, 3+ & 4	**	**
% fat	1982 females	ns	ns	82-83, females, 4+ & 5	ns	ns
	1982 males	ns	**	82-83, males, 4+ & 5	ns	ns
	1983 females	**	**	83-84, females, 3+ & 4	*	*
	1983 males	ns	*	83-84, males, 3+ & 4	*	ns

Table 4. Statistical tests comparing states and cohort. F-tests are summarized as not significant (ns), significant at 0.05 level (*), and significant at 0.01 level (**). In comparisons of states, tests for interactions (int) are significant where states differed, but not equally at all ages, while tests of main effects (main) are significant where states differed consistently across ages. In comparisons of year classes, tests for interactions are significant where year classes differ but not equally for all age-state combinations, while tests for main effects are significant where year classes differ consistently across age-state combinations.

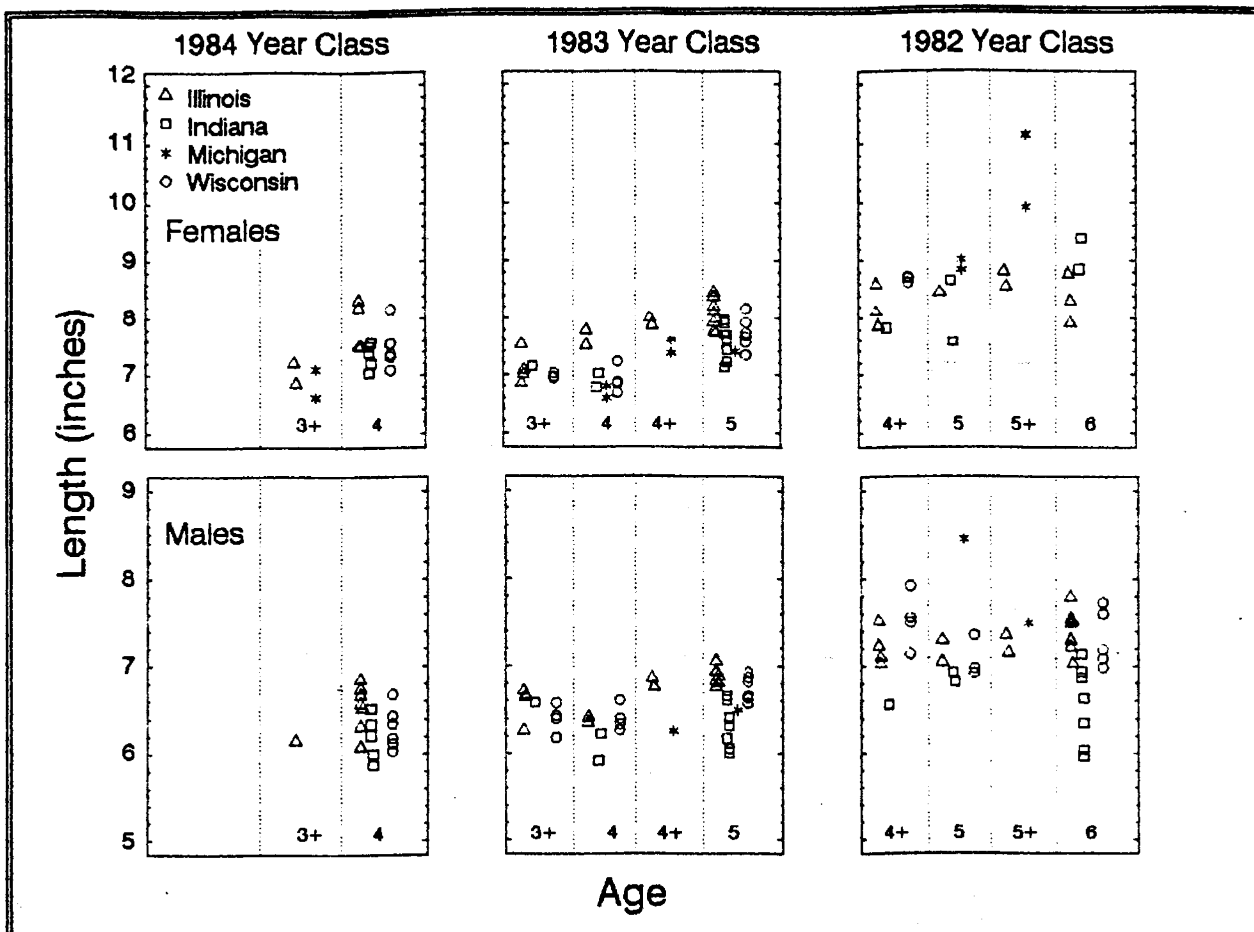

Figure 6. Weighted mean lengths. Data from deep (> 20 m) lifts offset slightly to the right within each set.

	females						males					
	3+	4	4+	5	5+	6	3+	4	4+	5	5+	6
82 IL			8.4	8.5	8.8	8.8			7.4	7.2	7.4	7.4
IN			7.8	8.7		8.9			6.6	6.9		7.0
MI				8.9	10.5					8.5	7.5	
WI			8.7						7.5	7.1		7.3
83 IL	7.2	7.7	8.0	8.1			6.5	6.4	6.9	6.9		
IN	7.2	6.8		7.7			6.6	5.9		6.5		
MI		6.7	7.5	7.4					6.3	6.5		
WI	7.0	6.9		7.7			6.4	6.4		6.8		
84 IL	7.2	8.0					6.2	6.5				
IN		7.3						6.4				
MI	6.9											
WI		7.5						6.3				

Table 5. Averages of weighted means of lengths (inches). Data from deep (> 20m) lifts are excluded.

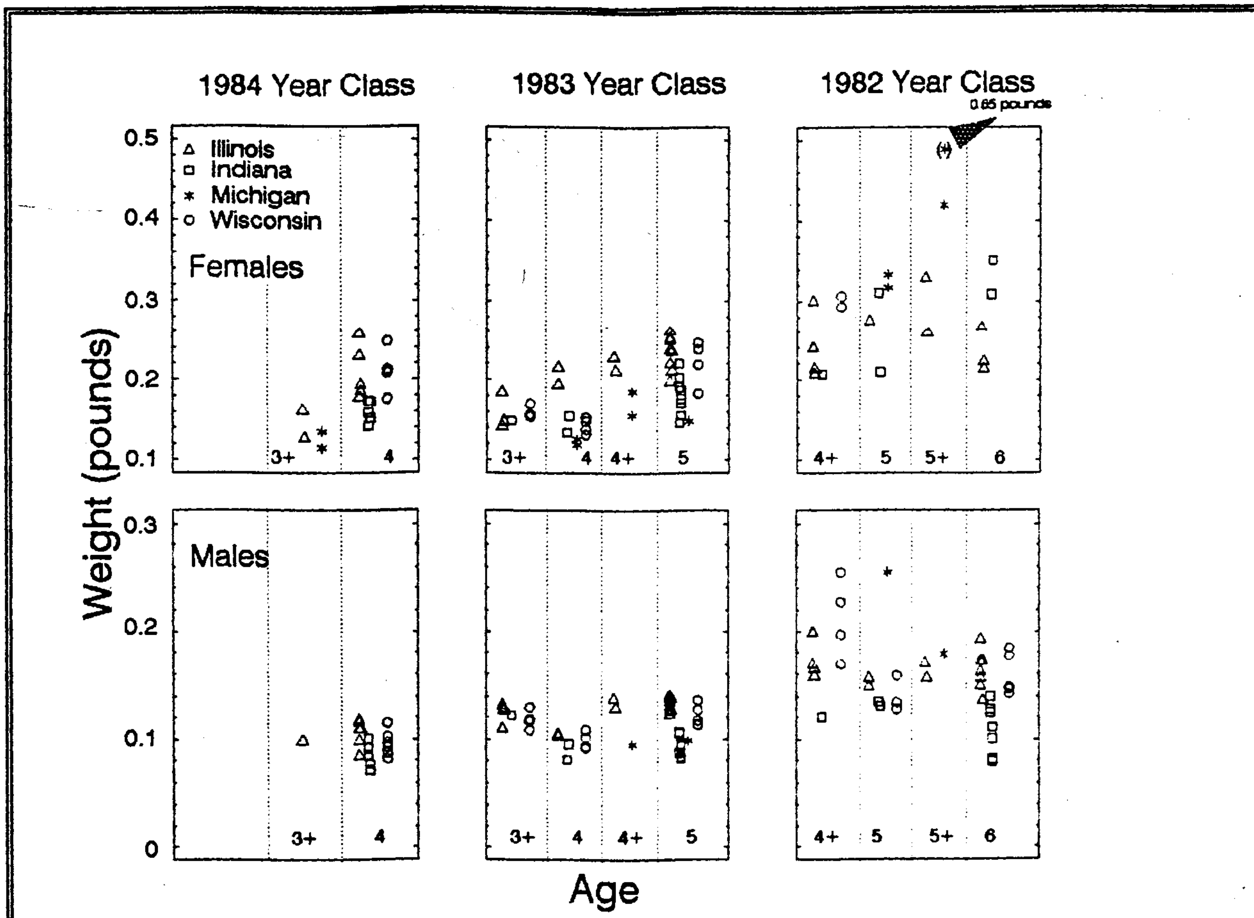

Figure 7. Weighted mean weights. Data from deep (> 20 m) lifts offset slightly to the right within each set.

	females						males					
	3+	4	4+	5	5+	6	3+	4	4+	5	5+	6
82 IL			.27	.28	.33	.27			.18	15	.17	.16
IN			.21	.31		.31			.12	.14		.13
MI				.33	.54					.26	.18	
WI			.30						.21	.14		.16
83 IL	.16	.21	.23	.24			.12	.10	.14	.13		
IN	.15	.13		.19			.12	.08		.10		
MI		.12	.17	.15					.10	.10		
WI	.16	.14		.22			.12	.10		.12		
84 IL	.16	.22					.10	.11				
IN		.16						.09				
MI	.13											
WI		.21						.10				

Table 6. Averages of weighted means of weights (pounds). Data from deep (> 20m) lifts are excluded.

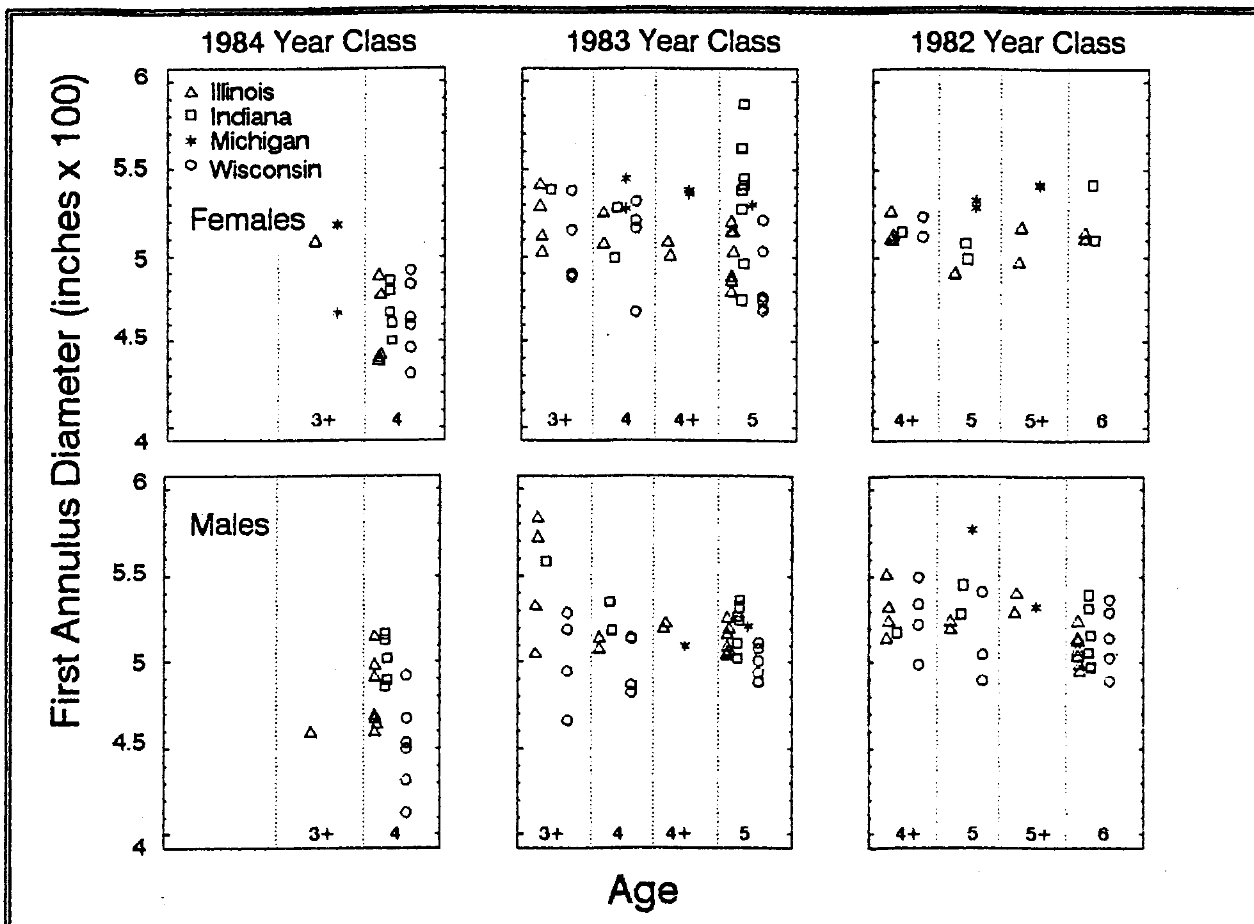

Figure 8. Weighted mean first-annulus diameters. Data from deep (> 20m) lifts offset slightly to the right within each set.

	females						males					
	3+	4	4+	5	5+	6	3+	4	4+	5	5+	6
82 IL			5.1	4.9	5.1	5.1			5.3	5.2	5.3	5.1
IN			5.1	5.0		5.3			5.2	5.4		5.1
MI				5.3	5.4					5.8	5.3	
WI			5.2						5.3	5.1		5.1
83 IL	5.2	5.2	5.0	5.0			5.5	5.1	5.2	5.1		
IN	5.4	5.1		5.3			5.6	5.3		5.2		
MI		5.4	5.4	5.3					5.1	5.2		
WI	5.1	5.1		4.9			5.0	5.0		5.0		
84 IL	5.1	4.6					4.6	4.8				
IN		4.7						5.0				
MI	4.9											
WI		4.6						4.5				

Table 7. Averages of weighted means of first-annulus diameters (inches * 100).

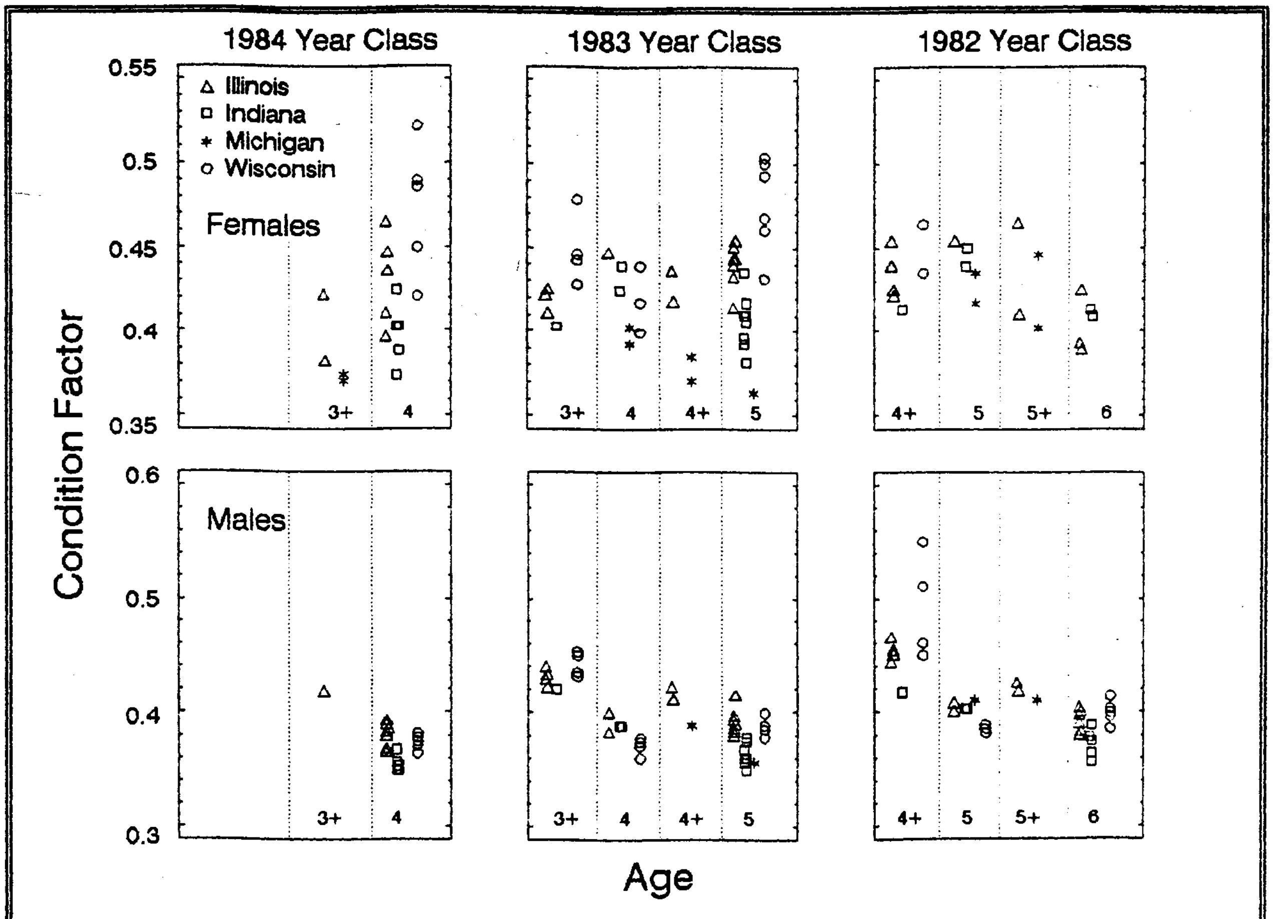

Figure 9. Weighted mean condition factors (pounds/inches³). Data from deep (> 20 m) lifts offset slightly to the right within each set.

	females						males					
	3+	4	4+	5	5+	6	3+	4	4+	5	5+	6
82 IL			.44	.45	.44	.40			.45	.40	.42	.39
IN			.41	.44		.41			.42	.40		.37
MI				.43	.42					.41	.41	
WI			.45						.49	.39		.40
83 IL	.42	.45	.43	.44			.43	.39	.42	.39		
IN	.40	.43		.41			.42	.39		.36		
MI		.40	.38	.36					.39	.36		
WI	.45	.42		.48			.44	.37		.39		
84 IL	.40	.43					.42	.38				
IN		.40						.35				
MI	.37											
WI		.48						.38				

Table 8. Averages of weighted means of condition factors (pounds/inches³).

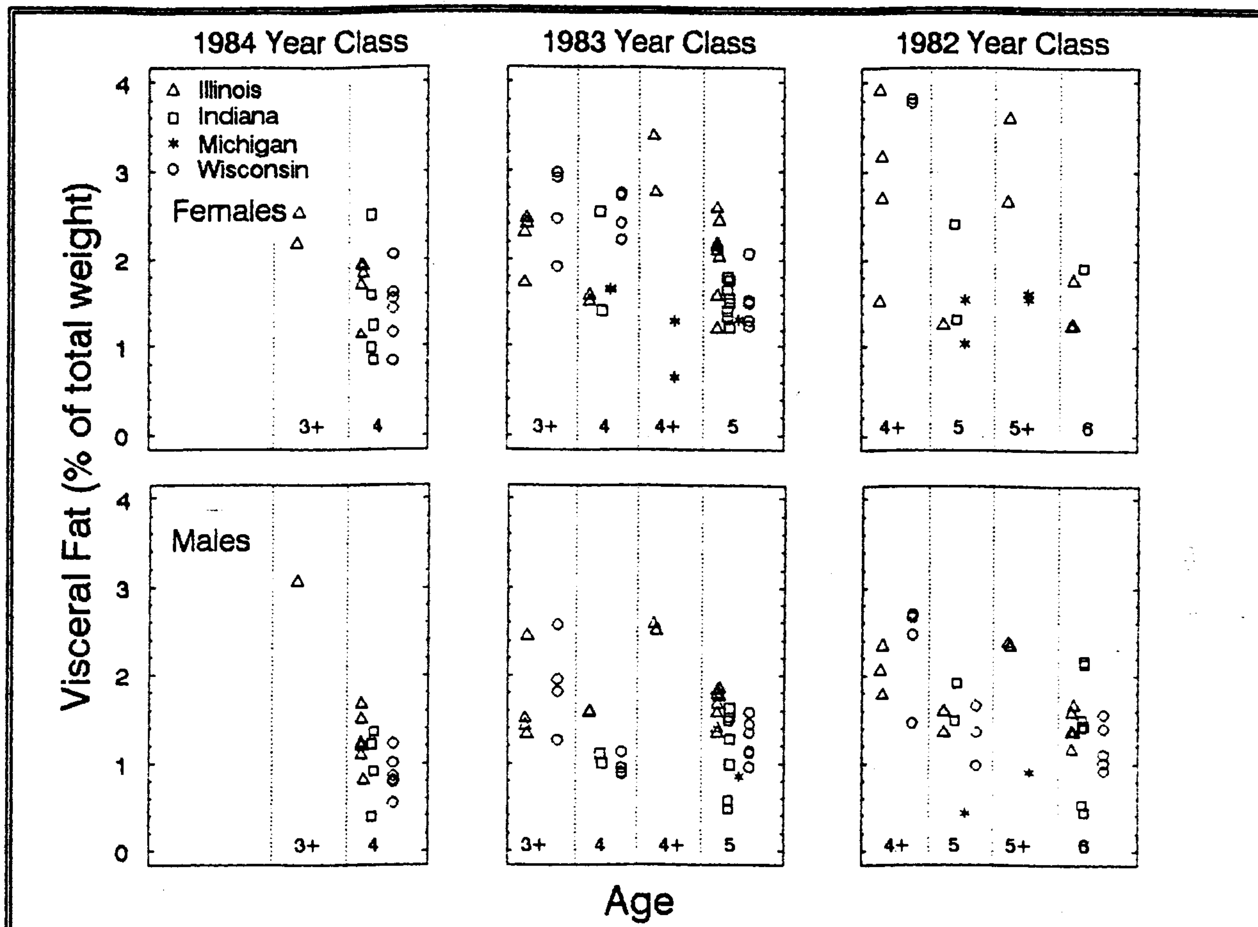

Figure 10. Weighted mean percentage visceral fat. Data from deep (> 20 m) lifts offset slightly to the right within each set.

	females						males					
	3+	4	4+	5	5+	6	3+	4	4+	5	5+	6
82 IL			2.8	1.3	3.1	1.4			2.1	1.5	2.4	1.4
IN				1.9		1.9				1.7		1.4
MI				1.3	1.6					0.4	0.9	
WI			3.8						2.3	1.3		1.2
83 IL	2.2	1.6	3.1	2.0			1.7	1.6	2.6	1.7		
IN		2.0		1.5				1.1		1.1		
MI		1.7	1.0	1.3						0.9		
WI	2.6	2.5		1.5			1.9	1.0		1.3		
84 IL	2.4	1.7					3.1	1.3				
IN		1.4						1.0				
MI												
WI		1.5						0.9				

Table 9. Averages of weighted means of percentage visceral fat.

Discussion

Aging Methods

The crack and burn method of aging fish using otoliths is superior to conventional methods involving scales or unprepared otoliths.

Three considerations support the the validity of ages determined in this study using the crack and burn method. First, ages so derived were consistent with independent assessments of the occurrence of a strong year class in 1983 in Michigan (Wells 1988), Indiana (McComish 1986), and Wisconsin (Belonger *et al.* 1989). Those assessments were based on age determinations made using scales, but because they involved very young fish (yearlings and 2-year-olds) it is likely that errors in age determinations were minimal. Second, ages derived using this method were verifiable; two independent readers agreed over 85% of the time (90% after training) and one reader obtained the same age from both otoliths 92 times out of 100 in independent readings of two sagittae. Third, diameters of the first annulus consistently fell within the range of heights of otoliths from fall yoy and early-summer yearlings. This supports the validity of first-annulus designations.

Ages determined from scales and unprepared otoliths not only were in poor agreement with one another (46% agreement in females and 57% in males), but, because both indicated a dominant year class in 1982, were in poor agreement with independent assessments of year class strengths.

Otoliths may not provide useful indices of growth after the first year.

Although I conclude that the crack and burn method can provide valid ages for yellow perch from Lake Michigan, it remains to be seen whether or not they can provide useful indices of growth after the first year. One problem is the physical structure of sagittae. As Figure 1 illustrates, the dorsal edges of sagittae are convoluted. I assume that the internal annuli follow those convolutions. When the otolith is cracked to show a tranverse cross section the spacing of annuli will depend on the orientation and location of the break. Since those things cannot be easily controlled, the spacing of annuli exposed to the reader will be highly variable. This problem may be alleviated by the use of lapilli. A second problem has to do with the relationship between otolith growth and somatic growth; the relationship between otolith size and fish size may depend on the growth rate of the fish, with slower growing fish having larger otoliths than faster growing fish of the same size. This was found in yoy striped bass by Secor and Dean (1989) and in yoy yellow perch by Post and Prankevicius (1987).

Relative Abundance and Sex Ratios

Catch rates presented here are unreliable indicators of relative abundance.

Catch rates by gill nets provide poor indices of relative abundance in schooling fish, such as yellow perch. Nevertheless, we might expect them to crudely reflect important features of the populations under study. In our study, where states differ markedly in the intensity of fishing, I would have expected to see catch curves decline most rapidly in the most heavily fished state, Indiana. Here, the catch curves tended to increase, and did so most rapidly in Indiana. I interpret this as confirming the poor utility of catch rates from gill nets as measures of relative abundance.

Sex ratios in Michigan were notably different than elsewhere (Table 3). In part, this is misleading because data from one male-dominated but incomplete lift in Michigan in the spring of 1988 were excluded from presentation here.

Size-at-age

Year-class strength influences size-at-age, but the effect may be moderated by fishing.

In all four states 4+ and 5-year-old fish from the strong 1983 year class were shorter, lighter, and thinner than those of the weaker 1982 year class. This suggests that intraspecific competition influenced size and condition under widely different levels of fishing pressure. It is tempting to suggest that since the effect was most pronounced in Michigan, where commercial fishing was banned, commercial fishing in the other states served to moderate this effect of increased abundance. This idea is supported by the fact that the lowest condition factors within the 1983 year class were found in fish from Michigan.

Size-at-age was least in Indiana despite warmer temperatures and good first-year growth, suggesting an impact by the fishery.

First-annulus diameters in Indiana were comparable to those in the other states. Despite this evidence for first-year growth comparable to the other states, Indiana males and females of the 1983 year class and males of the 1982 year class were shorter and lighter than those in the other states. That this occurs despite somewhat warmer water temperatures is not surprising in view of the intense size-selective commercial fishery that was present in Indiana.

But Indiana fish were also in poorer condition than contemporaries in Illinois and Wisconsin, suggesting that one or more other factors were also influential.

If the fishery in Indiana had reduced the average size-at-age in the yellow perch population by size-selective removal of fish, we might expect the survivors to benefit from an increased food supply and to be more robust than contemporaries in places where fishing was less intense. While yellow perch from Indiana had higher condition factors than those from Michigan, they compared poorly with fish from Illinois and Wisconsin where fewer fish were removed in the fishery. This suggests that although size-at-age in Indiana may have been reduced by the fishery, poor food availability or food quality may also have limited growth.

Lee's phenomenon is not conspicuous in any state, especially Indiana.

Lee's phenomenon occurs when the larger fish of a year class experience greater mortality than smaller fish. It would be expected in situations where size-selective fisheries strongly effect populations. In our data it would be expressed by declining mean first-annulus diameters in successive samples from each year class. There is no conspicuous evidence of it in any state. If anything, Lee's phenomenon is more pronounced in Illinois and Wisconsin than in Indiana.

The pattern of differences in first-annulus diameters suggests that intra-specific competition rather than alewife predation is the mechanism controlling mean size-at-age after one year, if yearlings and yoy compete for the same food supply.

If the average size of individual fish at the end of the first year is primarily affected by abundance through the mechanism of intraspecific competition, we would expect small first-annulus diameters in years of high abundance. We would expect the same thing if alewife predation influences mean size of survivors by selectively removing smaller, later hatching, or slower growing individuals, and if intensity of alewife predation determines yellow perch abundance.

The data are not fully consistent with either of these possible mechanisms, if yearlings and yoy yellow perch do not compete for the same food. First-annulus diameter is not clearly related to year class strength. Although first-annulus diameters of males were smaller in the strong 1983 year class than in the weaker 1982 year class, those of females were not. Moreover, first-annulus diameters were smallest for the 1984 year class which was probably weaker than that of 1983. This pattern is consistent with the hypothesis of intra-specific competition only if yearlings can deplete the food supply available to yoy.

First-year growth is not a dominating factor in later size-at-age.

Two features of these data point to this conclusion. First, even though first-year growth, as reflected by first-annulus diameter, in the 1984 year class was low, size-at-age in later years is comparable to that in other year classes. Second, fish from Indiana are shorter and lighter than contemporaries in other states despite the good first-year growth.

We have not fully explored the role of temperature.

The role of temperature in explaining the observed patterns has not been explored. We know that yellow perch in Indiana experience somewhat warmer water than those in the other three states. Perhaps, in conjunction with an intensive fishery the warmer thermal regime explains the phenomenon of smaller but thinner fish in Indiana waters. Warmer water stimulates faster growth but also generates a need for more food to maintain condition. Possibly in the absence of fishing we would see greater mean lengths but equally poorly conditioned fish.

Attainment of Objectives

This study was inititated with three objectives in mind:

To establish in southern Lake Michigan a system of coordinated data collection that utilizes the resources and common interests of fishery managers and scientists in four states. The establishment of the Lake Michigan Littoral Fisheries Research Group represents the attainment of this objective.

To assess the potential for sport and commercial fishing to influence yellow perch growth in Lake Michigan. It seems from the foregoing discussion that intense fishing may favorably influence growth rates but that other factors, probably related to food supply, are the dominant factors in that regard. The impact of intense fishing on size-at-age, through size-selective removals, is probably important.

To evaluate the accuracy, for yellow perch, of age determinations based on scales. Scales are not satisfactory indicators of age of yellow perch from Lake Michigan. Otoliths analyzes using the crack and burn method provided verifiable and valid ages.

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